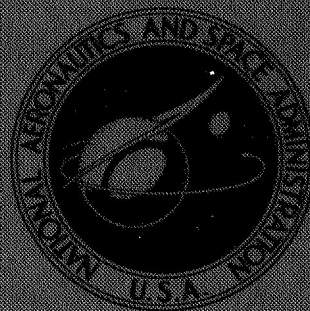


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FAST-NEUTRON BEAM IRRADIATION FACILITY IN THE NASA PLUM BROOK TEST REACTOR

*by John R. Smith, Erich W. Kroeger, Armen S. Asadourian,
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*Lewis Research Center
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SUMMARY

A facility built around the HB-6 beam hole of the NASA Plum Brook Reactor is described. The facility is designed for testing the effects of radiation on electrical components, such as semiconductor diodes, transistors, and integrated circuits, and for developing flux-measuring devices. The nuclear radiation environment in the test section of the facility has a range of 4.6×10^4 to 4.0×10^7 neutrons per square centimeter per second (>0.1 MeV); a thermal-neutron flux of 1×10^5 neutrons per square centimeter per second; and a gamma exposure rate of 1.3×10^4 to 9.8×10^4 roentgens per hour. This report discusses the method for varying the fast-neutron flux, the function of the biological shielding, the placement of specimens in the test section for irradiation, and the schemes for monitoring neutron and gamma fluxes during irradiation. A typical irradiation test of silicon diode rectifiers is described.

INTRODUCTION

An extension to the HB-6 beam hole of the Plum Brook Reactor was designed and installed at the reactor site. This facility was built primarily for the irradiation of electrical components, and it is described in order to acquaint potential experimenters with its features.

A collimated fast-neutron beam with a 15-inch diameter is generated in the test section of the facility for the irradiation of various electrical components, such as diodes, transistors, integrated circuits, semiconductor materials, batteries, and solar cells. However, experiments on radiation effects may be performed on any nonelectrical device or material, provided that the specimen fits within a cylindrical envelope 16 inches in diameter by 24 inches in length and that the specimen meets the reactor safety requirements.

During reactor operation, the fast-neutron flux (>0.1 MeV) in the beam may be varied from 4.6×10^4 to 4.0×10^7 neutrons per square centimeter per second by the use of water-filled attenuation tank compartments located between the test specimen and the radiation source (see table I). When the tank is used, gamma exposure rates vary from 1.3×10^4 to 9.8×10^4 roentgens per hour. Specimens can be irradiated by a higher fast flux of 1×10^8 neutrons per square centimeter per second by inserting a limited number of the specimens inside the empty duct portion of the thimble tank assembly (see fig. 1). All irradiations are performed, to eliminate any water seal problems, in a dry location outside the reactor tank. This is advantageous for tests in which the components are electrically energized during irradiation.

Electrical equipment available for power and instrumentation includes a 75-kilovolt-ampere transformer whose three-phase output is 208 volts at 60 cycles, and is transmitted through a breaker distribution panel. A motor-generator set with a three-phase output of 208 volts at 400 cycles, is also available. All test instrumentation is designed and supplied by the experimenter. A typical electric component irradiation test described in the appendix illustrates the testing techniques used in the HB-6 test facility.

DESCRIPTION OF FACILITY COMPONENTS

The major portion of the HB-6 test facility is located in quadrant B inside the containment vessel of the Plum Brook Reactor Facility, in the vicinity of the HB-6 thimble (see figs. 1 and 2). The closed end of this thimble is within $1/2$ inch of the beryllium reflector of the reactor core (ref. 1), and the thimble centerline lies in the core vertical midplane 10 inches above the core horizontal midplane. The open end of the thimble is accessible at the north face of quadrant B, where the nominal 15-inch-diameter neutron beam emerges and where the specimens to be irradiated are located to intercept the neutron beam. Surrounding the specimens is the biological shielding that protects personnel in quadrant B from neutron and gamma radiation during reactor operation.

The experiment test section, where specimens are irradiated in the neutron beam, is a cavity within the shielding array. Also located in this test section are devices to measure nuclear environment.

Associated electrical and electronic equipment for control and readout instrumentation is located both in quadrant B and in the experiment control room annex. Most of the experiment operation during irradiation is controlled from the control room annex located outside the containment vessel (fig. 2).

HB-6 Tank Assembly

Located within the HB-6 thimble is an array of cylindrical aluminum tanks (fig. 1).

This assembly consists of a shutdown tank, an attenuator tank, a thermal neutron absorber, and an empty duct. An annulus formed by the thimble inside surface and the tank assembly outside surface allows coolant water to remove gamma heat generated in the tank assembly during reactor operation.

The 6-foot-long shutdown tank is located at the core end of the thimble and provides gamma shielding for personnel working in the test section during reactor shutdown. This shielding is accomplished by filling the tank with deionized water. During reactor operation when test samples are being irradiated, the water in the tank is displaced by helium.

Immediately adjacent to the shutdown tank is the attenuator tank, 2 feet long and divided into four compartments, each a different length (shown in fig. 1). Compartments can be filled or drained in selected combinations to vary the fast-neutron flux during reactor operation (see table I).

A 1/4-inch-thick, spherically formed plate containing boron is located between the attenuator tank and the empty duct and serves as a thermal-neutron absorber. The plate cross section is a sandwich of a boron carbide dispersion in aluminum, clad on both sides and circumference with commercially pure aluminum. Boron was chosen (ref. 2) because of its ability to absorb thermal neutrons without leaving any significant residual induced radioactivity or without producing high-energy gamma radiation. The plate attenuates the thermal-neutron flux by a factor of 10^3 .

The last unit in the tank assembly is the empty duct that forms the water-tight seal between the tank-thimble annulus and the quadrant. Moreover, this duct makes possible the testing of components at higher flux levels (1×10^8 neutrons/(cm²)(sec) > 0.1 MeV) by permitting irradiation closer to the reactor core.

The water level in the shutdown tank and in each attenuator tank compartment is sensed by specially designed level indicators. These devices serve as "sight gages" by remotely sensing the empty or full condition of each tank and by energizing an indicating light in quadrant B and in the control room annex.

Facility Filling-Cooling System

An independent low-pressure cooling system was used for this facility instead of the reactor primary-cooling water. The functions of the filling-cooling system are to

- (1) Remove gamma heat generated in the shutdown and attenuator tanks
- (2) Remove heat generated in the thermal-neutron absorber plate
- (3) Cool the component test plate, if necessary because of electrical heat dissipated by the specimens
- (4) Fill and drain the shutdown tank and the attenuator compartments, as required

Basically this system supplies deionized water (120° F) at a constant pressure of 55 pounds per square inch absolute to a valve panel in quadrant B, as shown in figure 3. From this panel the water is directed by valves for filling, draining, or cooling operation, as required, up to a maximum flow rate of 25 gallons per minute. All water used eventually returns through a heat exchanger to a coolant reservoir. Helium for draining and purging any tank is supplied from standard gas bottles and when released is vented to the containment-vessel atmosphere.

A stainless-steel gravity fill tank is mounted on the quadrant wall above the facility and contains deionized water. This tank provides water for the shutdown tank in case the shutdown tank cannot be filled from the filling-cooling system; the volume of water in the gravity fill tank is sufficient to fill the shutdown tank completely. The stainless-steel tank is filled directly from the reactor deionized water system and can be directed into the shutdown tank by a manually operated ball valve. A float switch is incorporated in the tank to verify that it contains the proper amount of water at all times.

For irradiation tests where the test components are electrically energized, the electrical heat must be dissipated. The excessive temperature of the test components may be limited by maintaining cooling flow through coolant tubes attached to the test plate. This cooling water is available from the facility filling-cooling system.

Shielding

In order to accomplish the basic objectives of the irradiation program, it is necessary to expose the test components to the neutron beam emanating from the HB-6 beam hole. Test components are mounted on a circular plate that is supported so that it intercepts the neutron beam; thus, all components are irradiated according to the flux variation over the beam cross section. Surrounding the plate is biological shielding, which protects personnel in the quadrant from neutron and gamma radiation during reactor operation. The shielding array, 17 feet long, 10 feet wide, and 14 feet high, is shown in figures 2 and 4. It consists of stacked blocks formed from paraffin-filled steel and aluminum shells. The blocks are designed to interlock in such a manner as to eliminate any radiation streaming between block interfaces. Most of the shielding blocks are permanently stacked; the only blocks periodically removed and replaced are those providing access to the test cavity. A typical shielding block, shown in figure 5, is constructed from mild steel and aluminum and is filled with a borated paraffin mixture. Conduit and water pipes are built into some of the blocks to permit electrical power and cooling water to enter the test cavity.

Test Section

A cavity inside the biological shielding array, into which the HB-6 neutron beam passes, is designated the test section. A cross section is shown in figure 6. The components to be irradiated are positioned in this cavity and are connected to electrical power, readout instrumentation, and cooling water. By removing three shielding blocks, personnel gain access to the test section during reactor shutdown periods. A limited number of specimens and/or radiation detectors can be inserted for irradiation during reactor operation by using the foil holder and shutdown shield slot. Equipment generally located in the test section is described below and is illustrative of equipment that can be used in the test cavity.

Test cradle. - A typical test configuration is shown in figure 6. This unit consists of a base, a T-slot bar that plugs into the base, and yokes for holding a test plate and nuclear instrumentation sensing devices. Most of the test-cradle parts are constructed of aluminum.

Ion chamber mount. - Two gamma-monitoring ion chambers are supported by a circular aluminum plate attached to a test-cradle yoke. The position of these chambers on the plate is shown in figure 7.

Fission counter mechanism. - A mechanism, mounted on a yoke, supports a neptunium fission counter. An electric motor (fig. 8) is used to remotely position the fission counter along the vertical centerline of the HB-6 beam. A helical potentiometer driven off the drive shaft indicates the vertical position of the counter in the experiment control room annex, where the mechanism is controlled.

X, Y-traverse mechanism. - A positioning device is attached to the shutdown shield support and is used to remotely position flux-sensing devices anywhere within the 15-inch-diameter neutron beam cross section. The mechanism uses vertical and horizontal (X, Y) drives. The horizontal motion (fig. 9) is provided by means of a guide block that travels along a motor-driven jack screw, while a parallel guide rod counteracts any torque resulting from friction in the rotating jack screw. Each end of the horizontal jack screw is supported by a bearing block with the electric drive motor on one block. Both of these bearing blocks ride up or down on two vertical jack screws, which are synchronized through bevel gearing and are driven by another electric motor. Position indication of the carrier, to which are attached the flux-sensing devices, is provided by two helical potentiometers. Control and positioning of the X, Y-traverse mechanism is done from the experiment control room annex.

Shutdown shield. - A rectangular opening (figs. 4 and 6) in the top of the biological shielding array contains a vertical guide tube, rectangular in cross section, that extends into the test section and permits the insertion of a shutdown shield. The shutdown shield is a $2\frac{3}{4}$ -inch-thick, 90-percent-tungsten-alloy slab that covers the HB-6 beam opening

during reactor shutdown periods. The purpose of this shield is to augment the gamma shielding provided by the water-filled thimble tanks. Attached to this shield is a thinner mild-steel slab that extends above the top surface of the biological shielding array to permit handling when the shield is manipulated.

During reactor operation, the shutdown shield is replaced by an aluminum shell that contains borated paraffin. This shell fills the guide tube to maintain integrity of the biological shielding; however, it does not cover the HB-6 beam opening as shown in figure 6.

Foil holder. - A foil holder can be positioned perpendicular to the HB-6 beam in the test section and permits irradiation of activation foils for determining flux levels and spectra. Basically, the foil holder includes a foil plate and an insertion fixture (fig. 10). A thin aluminum disk, $16\frac{1}{2}$ inches in diameter, serves as the foil plate. One hundred and twenty-one depressions $1/2$ inch in diameter are arranged in radial pattern on the plate to accommodate standard foils and pellets. Pressure-sensitive tape is used to attach the foils to the plate at selected depression locations. The foil plate with the attached foils is locked to the insertion fixture, and the entire assembly is lowered into a slot adjacent to the shutdown-shield guide tube. Final positioning of the insertion fixture occurs when it enters guides attached to the face of the shutdown-shield guide tube. When in position for foil irradiation, the insertion fixture lifting handle extends above the top of the shielding array. In this manner, foils can be inserted or removed from the test section while the reactor is operating and without disrupting an irradiation experiment in the facility.

Nuclear Instrumentation

When the HB-6 facility was ready for operation, the nuclear environment in the test section was determined before any components were irradiated. Further flux measurements were made during irradiation experiments, following the initial flux survey. These measurements were made by using activation foils and pellets, thermoluminescent dosimeters, p-n semiconductor diodes, a fission counter, and ion chambers.

Activation foils and pellets. - Standard activation foils and pellets are used to determine the time-integrated neutron flux in the 15-inch neutron beam. These devices are placed on the foil holder (described in the previous section) and inserted into the test section for exposure. After a predetermined exposure, the foil holder is withdrawn from the test section, the foil plate is removed from the insertion fixture, another prepared foil plate is attached to the fixture, and the assembly is inserted for another exposure. The exposed foils are removed from the plate and taken to the Plum Brook Reactor counting facility, where their subsequent activity is noted. Calculations made by using the activity measurements subsequently yield neutron flux integrated over the foil exposure

time. The neutron flux spectrum is defined by using foil materials that produce different threshold energy levels when activated.

Thermoluminescent dosimeters. - Gamma fields in the HB-6 beam were mapped with thermoluminescent dosimeters (ref. 3) mounted on the foil holder. These dosimeters, small capsules containing lithium fluoride powder, absorb and store gamma energy when exposed to gamma radiation. After exposure, the powder from the capsules is placed in a small induction furnace readout system that heats the powder and drives off the stored energy in the form of light. This light, which is related to the gamma dose, is detected by a photomultiplier tube and meter, and from these data the gamma dose is calculated.

Semiconductor diodes. - Like the foils, the p-n semiconductor diodes (ref. 4) are also used to measure time-integrated neutron flux. The diodes are mounted on the foil holder and exposed for a few hours to the neutron beam in the test section. A measurement is then made of the radiation-induced increase of the forward voltage when it is read at constant current. A correlation is provided to relate this voltage reading to the integrated neutron flux.

Fission counter. - The devices described previously do not provide immediate flux information since they must be removed from the test cavity and counted, and the flux must be calculated from their activity or from the change in their characteristics. Instantaneous neutron-flux information is obtained by using a fission counter and suitable readout instrumentation. The fission counter used is essentially an ion chamber surrounded by a fissionable material such as neptunium. This neptunium-coated fission counter is mounted on the fission counter mechanism previously described (p. 5). The counter is moved in a vertical direction to traverse the flux field, and its output provides correlation and redundancy with foil measurements. Instrumentation associated with the fission counter is shown in the block diagram of figure 11.

Ion chambers. - For immediate gamma-flux measurements, two commercial, miniature ion chambers (ref. 5) are mounted on an aluminum plate in the test section. These gamma-sensitive instruments are used in a gamma exposure rate range of 10^4 to 10^9 roentgens per hour. The 1/4-inch-diameter, $2\frac{1}{2}$ -inch-long chambers consist of concentric cylinders, or electrodes, filled with argon gas. Readout instrumentation for these chambers is shown in figure 11.

Nuclear Environment

The HB-6 fast-neutron flux (0.3 MeV) in the test section was obtained from sulfur-pellet activation measurements and was 4×10^7 neutrons per square centimeter per second. Gold foils were exposed to measure the thermal-neutron flux, which was 1×10^5 neutrons per square centimeter per second. Threshold foils indicate a neutron spectrum of higher

energies than a fission spectrum. Thermoluminescent dosimeters were used to detect a gamma field of 9.8×10^4 roentgens per hour. Fast-neutron-flux and gamma-dose rates for various attenuator tank fill combinations are shown in table I.

Readings taken on the HB-6 centerline in the test section with all thimble tanks filled and with the shutdown shield in place indicated a gamma exposure rate of 12 milliroentgens per hour 4 hours after the reactor was shut down. Twenty-four hours after shutdown, the reading was 3 milliroentgens per hour. This radiation level permits safe working conditions in the test cavity.

CONCLUDING REMARKS

A description of the HB-6 irradiation facility at the NASA Plum Brook Reactor was presented. The facility is designed to irradiate many small electric or electronic components while they are operating, as in a circuit. Irradiation is accomplished in a fast-neutron flux (0.1 MeV) that ranges from 4.6×10^4 to 1×10^8 neutrons per square centimeter per second and with a gamma exposure rate that ranges from 1.3×10^4 to 9.8×10^4 roentgens per hour. The thermal flux in the test section is 1×10^5 neutrons per square centimeter per second. Primary components of the facility consist of a support structure for test specimens, a neutron-beam attenuator and thermal-neutron absorber for providing the desired flux, a tank filling-cooling system, and associated electrical and instrument systems. This facility has been in operation since early in 1965. Various component and foil irradiations have been performed including a silicon diode test during which the specimens were irradiated while each was operating at a current of 10 amperes. Immediate tests that have been planned include the irradiation of zener diodes and silicon-controlled rectifiers.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, December 15, 1966,
120-27-04-35-22.

APPENDIX - TYPICAL ELECTRIC COMPONENT TEST

This test program was designed to accomplish two main objectives:

- (1) To study the effects of a nuclear environment on diode rectifiers while they are operating under different power conditions
- (2) To contribute information on the operation of nuclear space power system components under a simulated nuclear environment

The test program was conducted at the Plum Brook Reactor Facility in the HB-6 beam hole. Associated equipment and instrumentation were located in quadrant B and in the experiment control room annex. The test involved the irradiation of 50 high-reliability S1N1189 rectifiers with a fast-neutron flux of approximately 4×10^7 neutrons per square centimeter per second and a gamma field of 10^5 roentgens per hour. During the test, the rectifiers were operated under alternating- and direct-current conditions at a predetermined stud temperature. At selected times throughout the irradiation cycle, the alternating- and direct-current power was shut off and each diode rectifier was monitored by numerous test circuits to detect any change in the electrical characteristics.

Changes that were noted during the test were an increase in the forward voltage drop and reverse leakage currents, and a decrease in the photoelectric current.

Test Instrumentation

Fifty diode rectifiers (figs. 12 and 13) were stud-mounted on an aluminum plate. Aluminum tubing was brazed to one side of the plate, through which cooling water flowed to remove heat generated by the electrically energized diodes. Each diode was electrically isolated from the plate. All wiring to and from the diodes was terminated in quick-disconnect fittings to facilitate installation and removal. An assembled diode test ready for installation in the test section is shown in figure 13.

Test Operation

The major requirement for the diode irradiation test was to subject 50 diodes to continuous operation during irradiation and to measure any change in characteristics. To accomplish this, each diode was wired in series with a two-pole, single-throw mercury relay (fig. 14).

Normal operating mode. - In the normal operation mode, which was applied to the diodes between data acquisitions, the 50 diodes were divided into three groups, each group to operate under a specified power condition. Thirty diodes of the first group re-

ceived power from a 400-cycle motor-generator source. Each diode had the equivalent of 10 amperes average current applied in the forward direction and a 100-volt peak applied in the reverse. The 30 diodes were coupled to the three-phase motor-generator by transformers, 10 diodes to each phase. The output of each phase transformer was modified through a silicon-controlled rectifier (SCR) circuit to supply the forward and reverse power (described previously), for 10 diodes wired in parallel. In series with each diode was a variable-power resistor, an ammeter, a relay, and a fuse. The resistor-ammeter combination provided continuous control and monitoring of forward current to each diode, while the fuse between the relay and diode provided continuous overload protection.

A group of 10 other diodes was operated in the forward direction at 10-amperes direct current (power supply 4, fig. 14). Each of these diodes was wired in parallel and used the control and protection identical to circuits in the 400-cycle power mode.

The remaining group of 10 diodes received power from a reverse bias of 100 volts direct current (power supply 3, fig. 14). The diodes were wired in parallel with a fuse in series with each.

Test operating mode. - During the test-mode portion of the test, all control and data acquisition, except for reverse-current measurements, were accomplished from the control room annex. Application of the required measuring conditions to the diodes by various power supplies and resistor networks located in quadrant B was activated from the control room annex. These power sources were connected to the normally open side of the mercury relays. A scanning system was used to record the test mode, to switch the mercury relays, and to measure and record all pertinent information. The data were recorded with a digital printout and a punched paper tape. The punched tape was subsequently used with a computer program to tabulate the data.

A forward-voltage-current curve was plotted from the test data for each diode. A direct-current power supply (power supply 1, fig. 14) and a network consisting of appropriate resistors were used to measure the electrical characteristics. The exact values of voltage and current were determined by measuring the voltages across the known resistors in the network.

Reverse characteristics were monitored throughout the test by a test circuit designed for this measurement. This circuit consisted of a voltage source and a picoammeter. Each diode was connected to this circuit and subjected to a reverse bias of 100 to 600 volts direct current in 100-volt steps. The corresponding leakage current was manually read on the picoammeter. This operation was performed in quadrant B just outside the shielding, as near as possible to the diodes, to keep leakage losses at a minimum.

In order to note any changes in the slope of the diode reverse breakdown during irradiation, an X, Y-plotter was used to trace the voltage-current curve. The voltage applied to the diode from the experiment control room annex through a motor-driven variable-

power supply served as the X-input to the plotter. The Y-input, or current axis, was determined by the voltage across a resistor in series with the diode.

Diode stud temperatures were monitored by thermocouples cemented to each diode case. These thermocouples were referenced to a 32° F oven in quadrant B and their outputs were measured in the control room; each diode temperature measurement was selected by the scanner.

A detailed analysis of each diode was made before and after irradiation in the laboratory. Examined were the forward, reverse, and capacitance characteristics, which were taken at room and elevated temperatures. The following ranges were covered:

Temperature, °C	25 to 125
Forward current, A	0 to 5
Reverse voltage, V	0 to 1500
Capacitance, pF	0 to 300

These measurements were made both point by point and by a continuous curve.

The photoelectric effect due to radiation was observed on 10 diodes. A direct correlation between radiation intensity and photoelectric output was noted.

Results

Three main areas of change were observed during the test program:

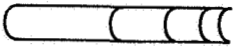
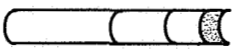
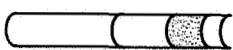
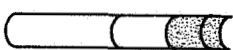
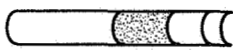
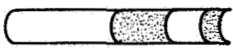
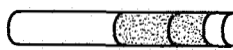
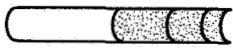








- (1) The forward voltage drop increased.
- (2) The reverse leakage current increased.
- (3) The photoelectric current decreased.

Associated with these three changes was an increase in the stud temperature at normal operating conditions (p. 9).

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TABLE I. - VARIATION OF FAST-NEUTRON FLUX AND GAMMA-
EXPOSURE RATE WITH USE OF ATTENUATOR TANK

Attenuator-tank configuration	Water thick- ness, in.	Maximum neutron flux in test section, neutrons/(cm ²)(sec) (a), (b)	Maximum gamma exposure rate in test section, R/hr (b)
	0	4.0×10^7	9.8×10^4
	$1\frac{1}{2}$	2.9×10^7	9.0×10^4
	3	1.5×10^7	7.8×10^4
	$4\frac{1}{2}$	1.1×10^7	6.9×10^4
	6	6.0×10^6	6.3×10^4
	$7\frac{1}{2}$	4.0×10^6	5.1×10^4
	9	2.3×10^6	4.3×10^4
	$10\frac{1}{2}$	1.3×10^6	3.5×10^4
	12	7.2×10^5	2.9×10^4
	$13\frac{1}{2}$	5.0×10^5	2.6×10^4
	15	2.8×10^5	2.2×10^4
	$16\frac{1}{2}$	2.1×10^5	1.8×10^4
	18	1.1×10^5	1.6×10^4
	$19\frac{1}{2}$	8.0×10^4	1.5×10^4
	21	6.1×10^4	1.4×10^4
	$22\frac{1}{2}$	4.6×10^4	1.3×10^4

^a>0.1 MeV.

^bBased on measured values.

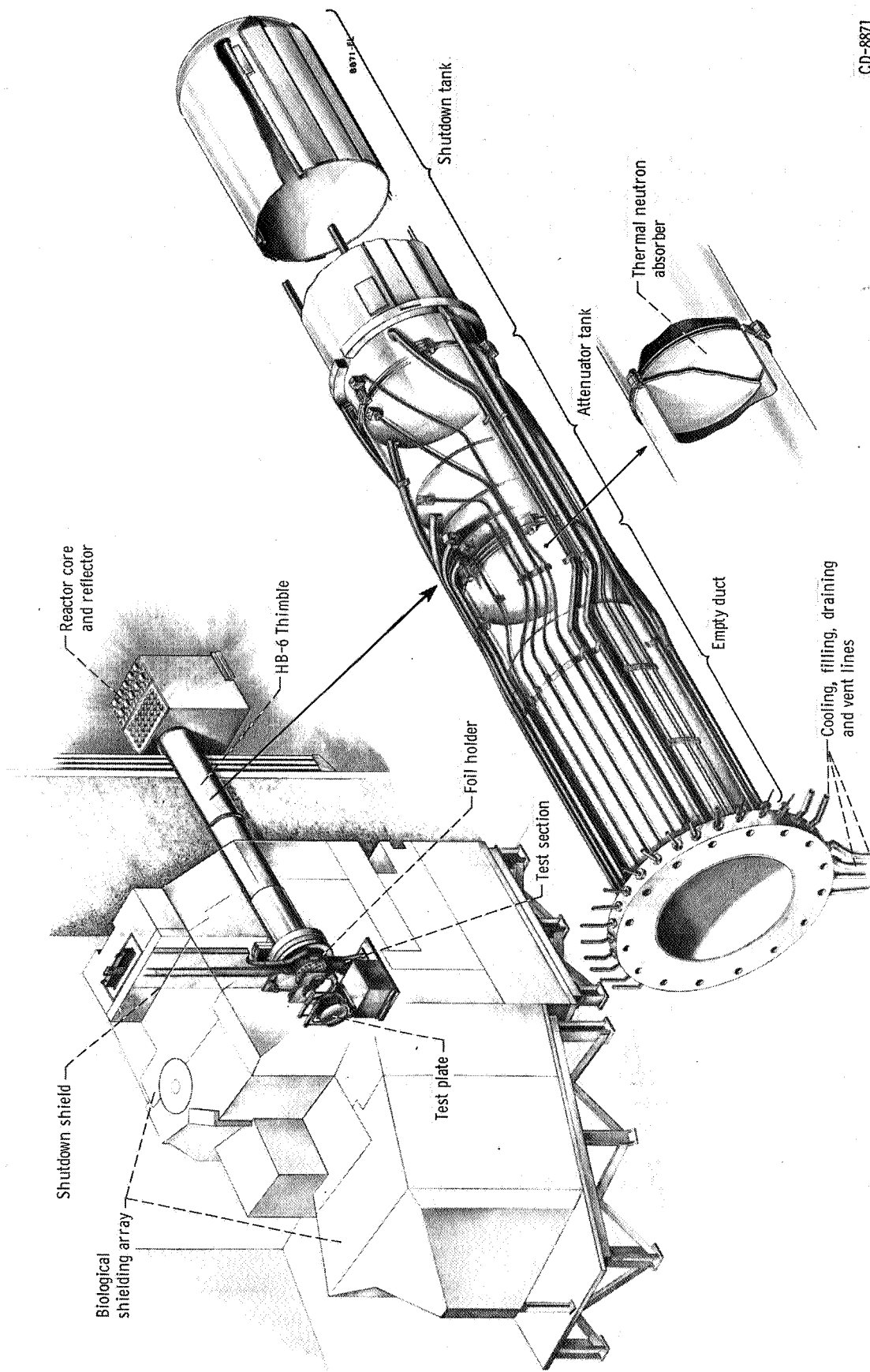


Figure 1. - HB-6 thimble tank assembly.

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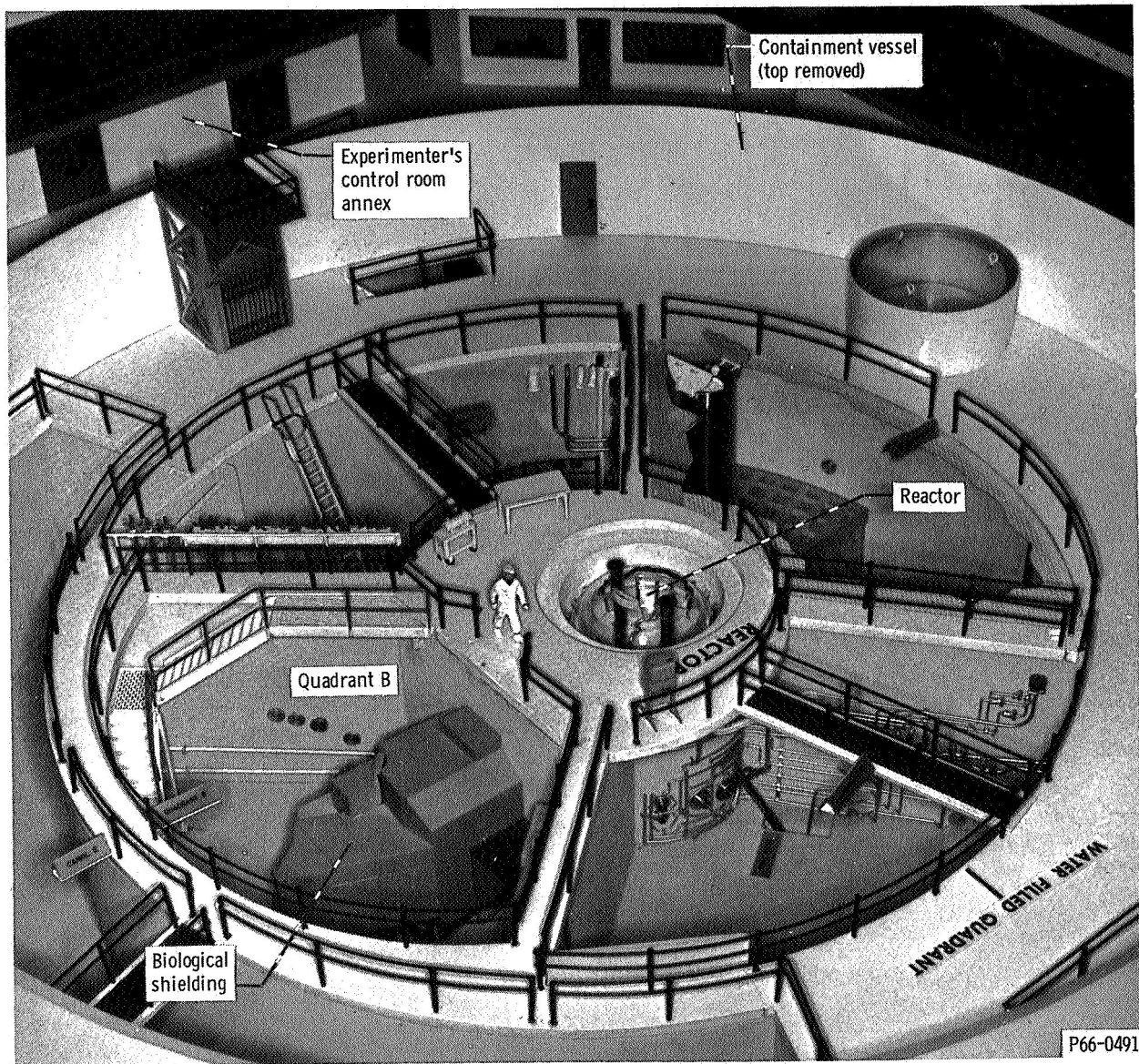


Figure 2. - Plum Brook Reactor Facility.

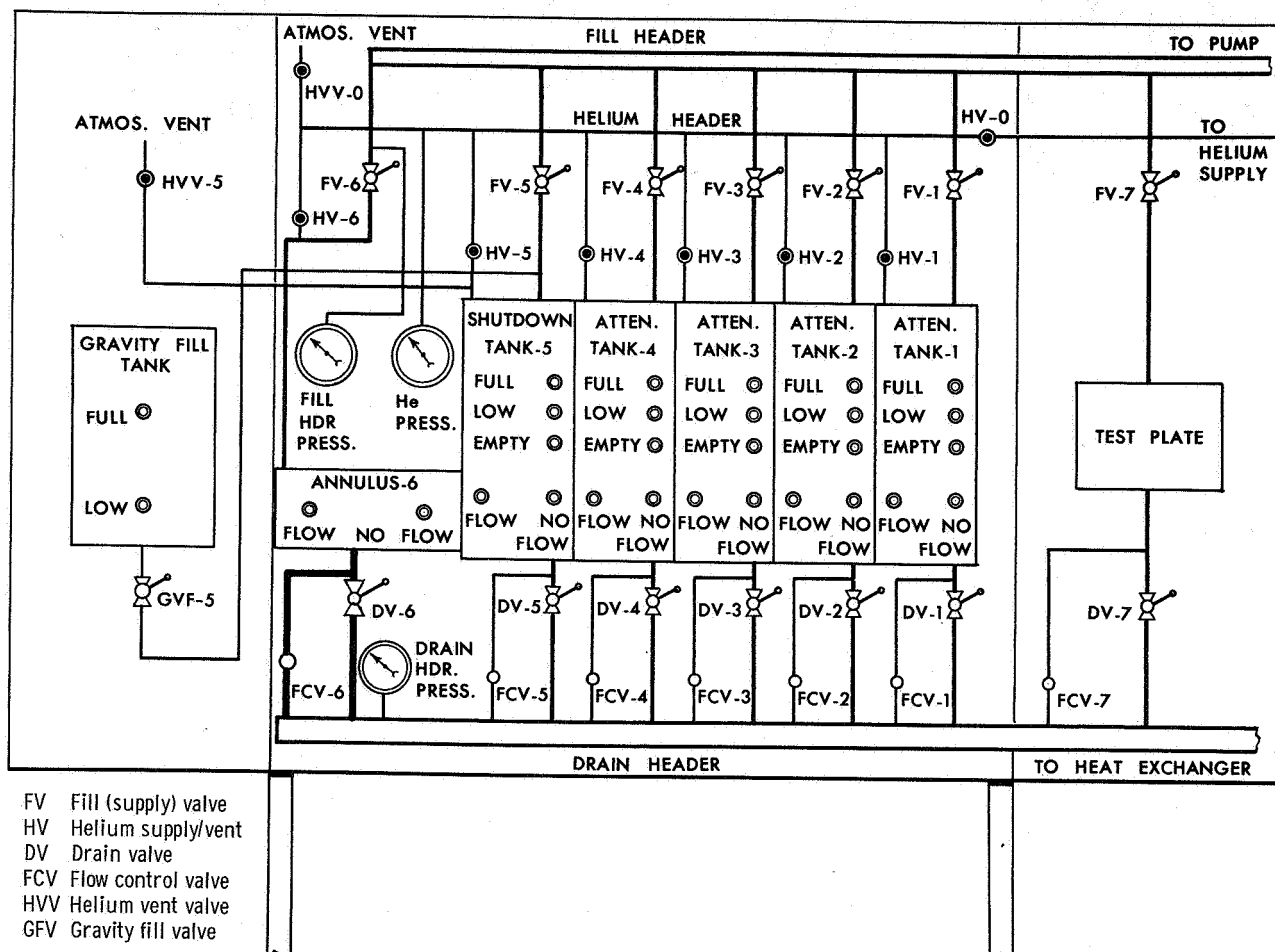


Figure 3. - Schematic of filling-cooling system on valve panel.

CD-8869

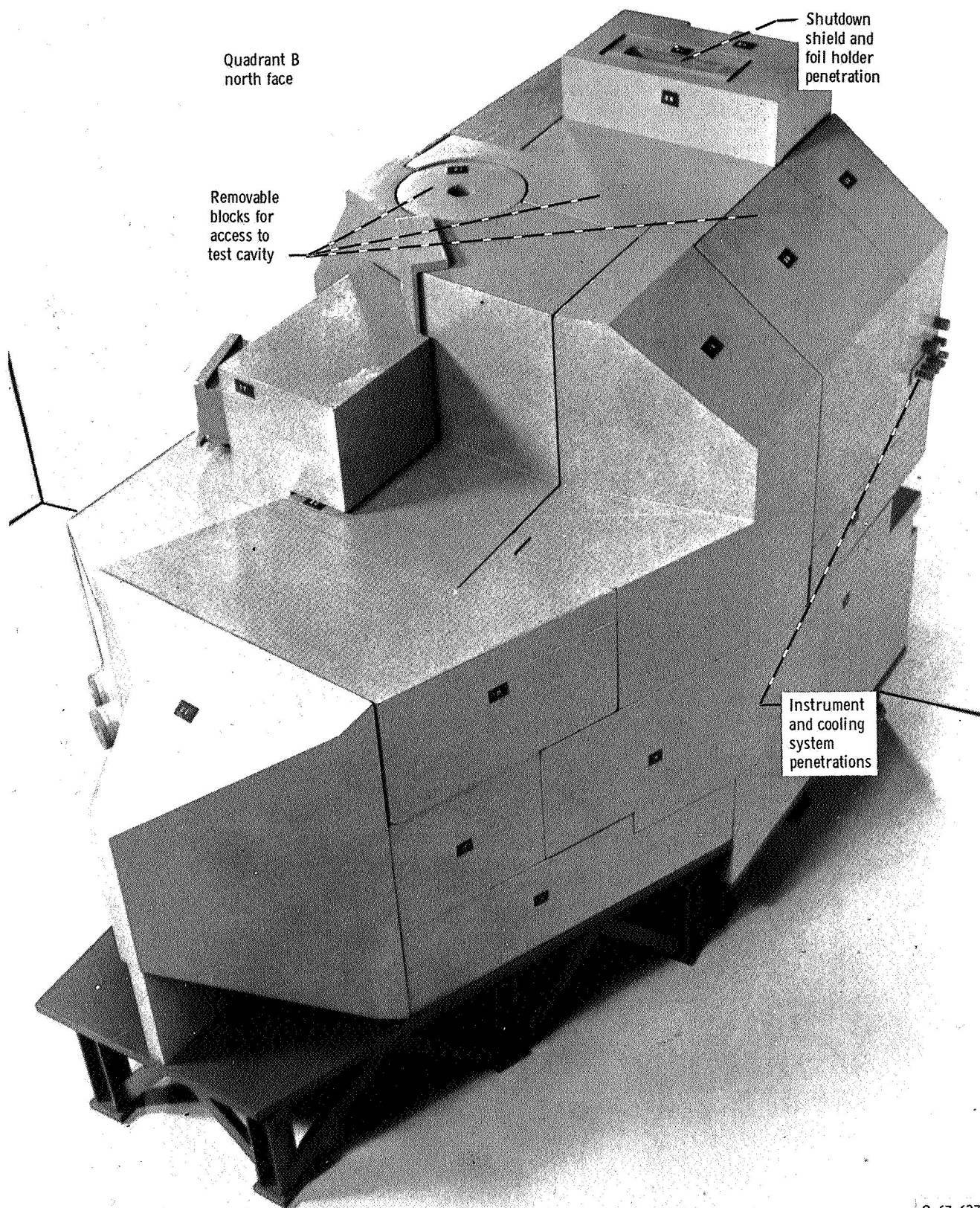
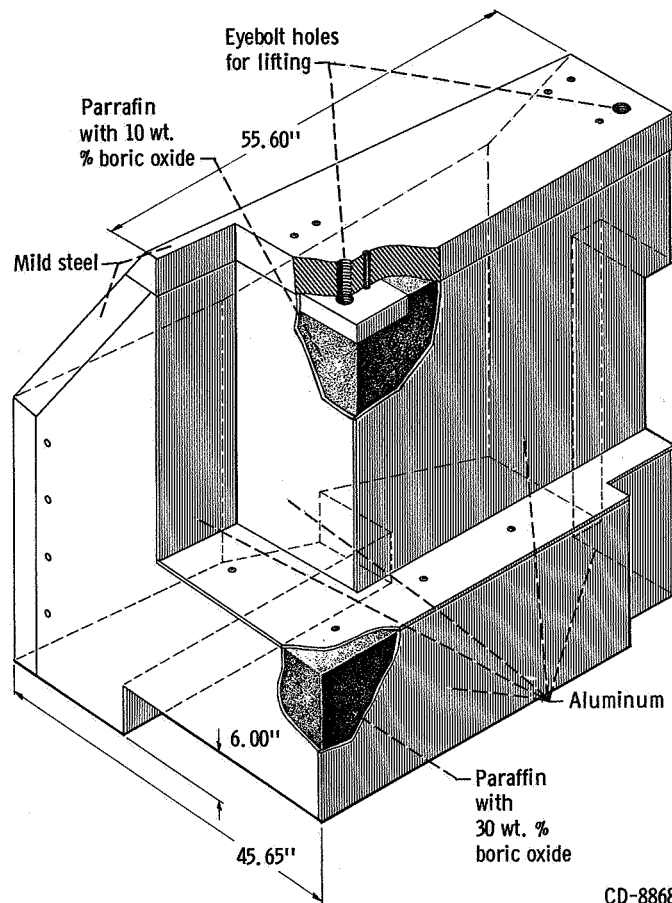


Figure 4. Biological shielding.

C-67-637



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Figure 5. - Typical biological shielding block.

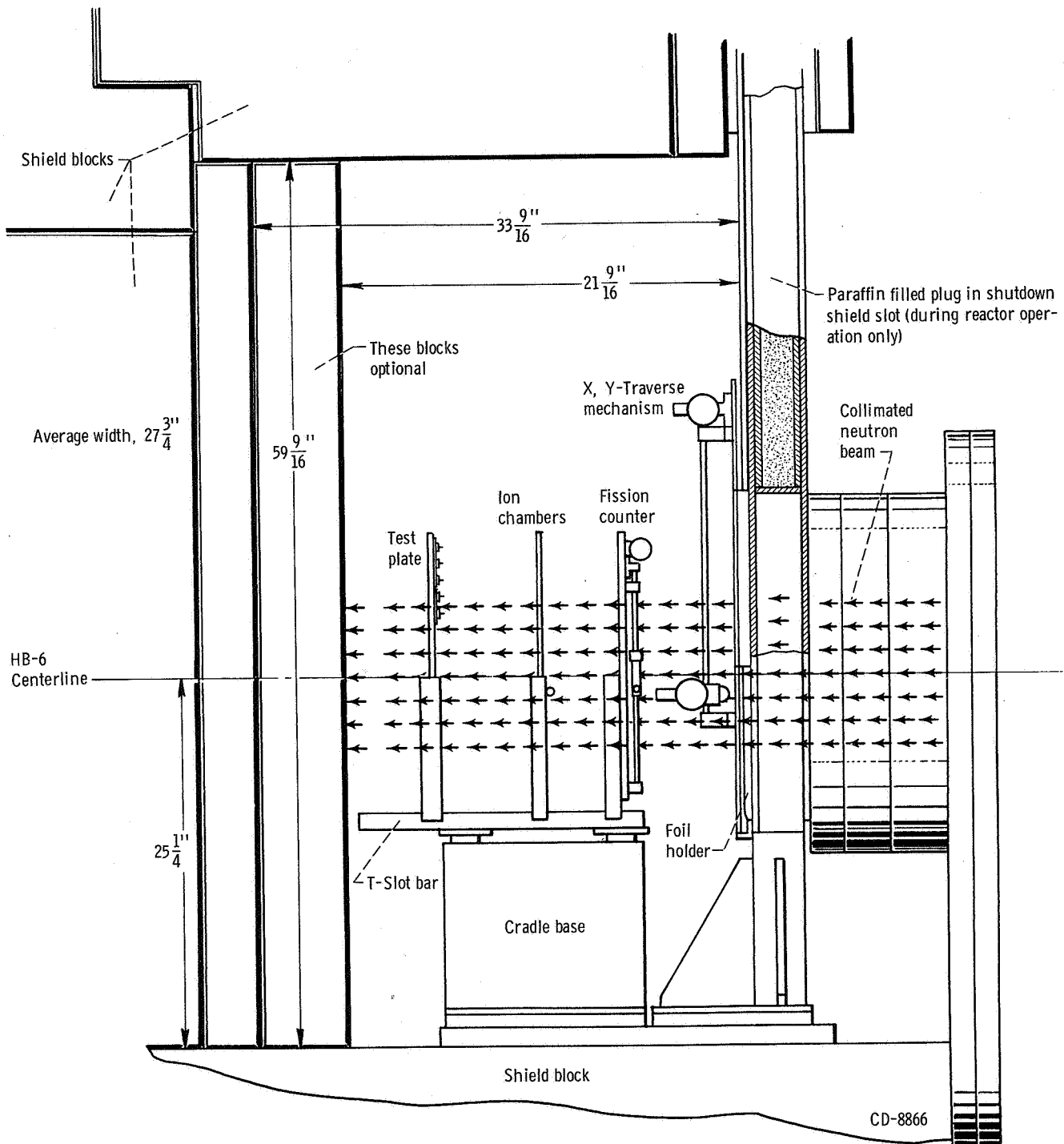


Figure 6. - Test section.

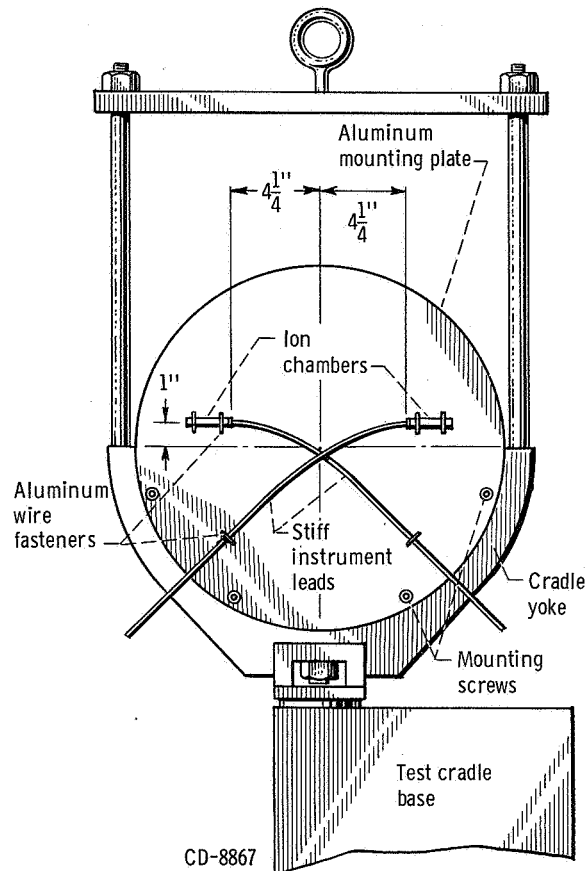
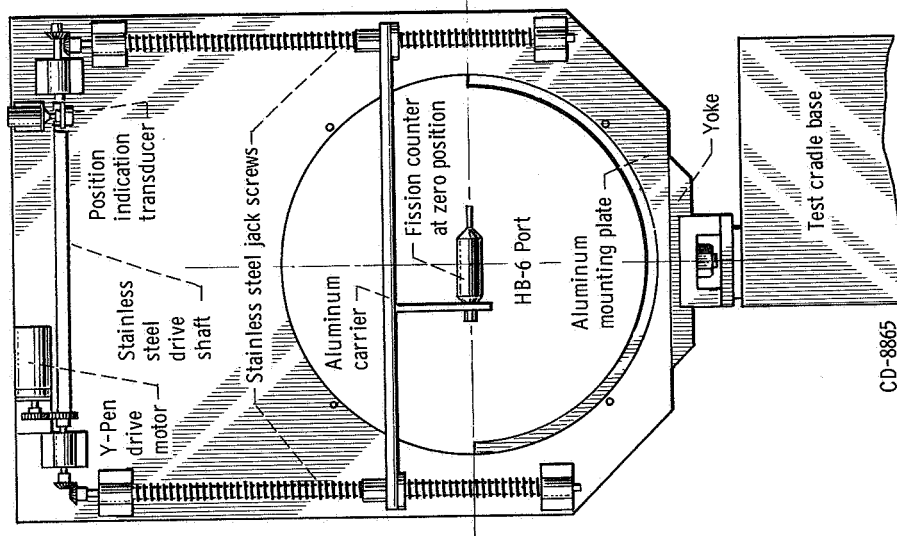
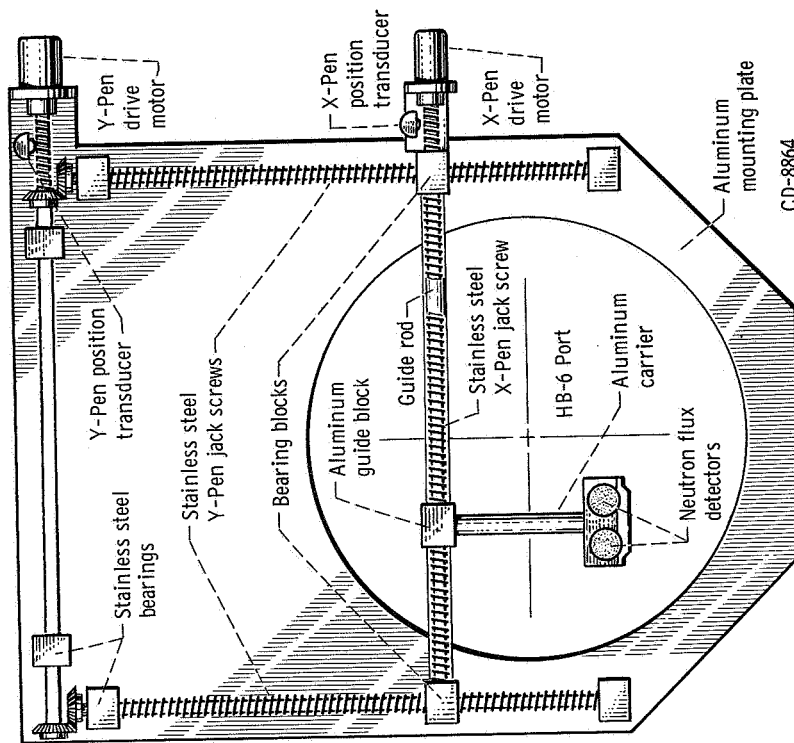


Figure 7. - Ion-chamber positions.



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Figure 8. - Fission counter mechanism.



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Figure 9. - X, Y-Transverse mechanism.

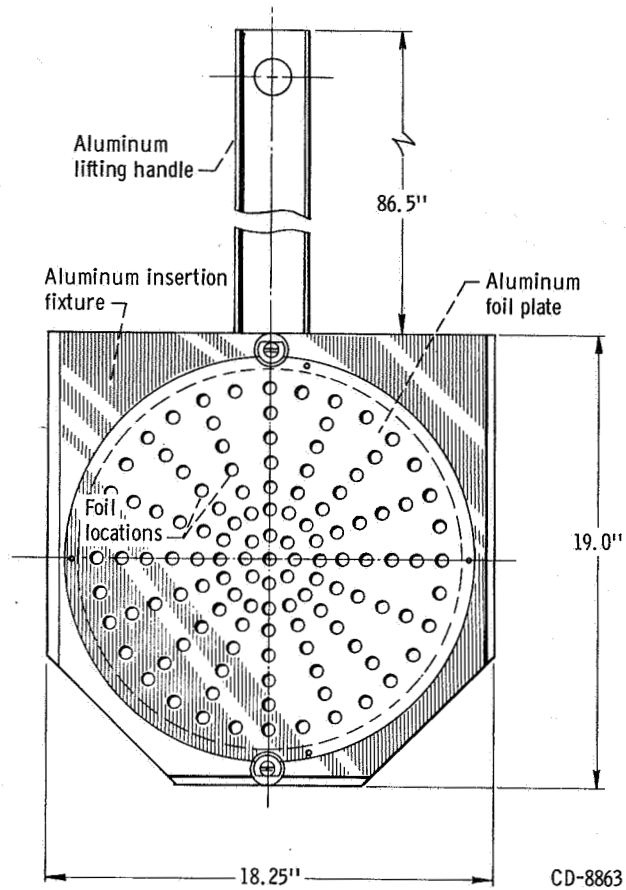


Figure 10. - Aluminum foil holder.

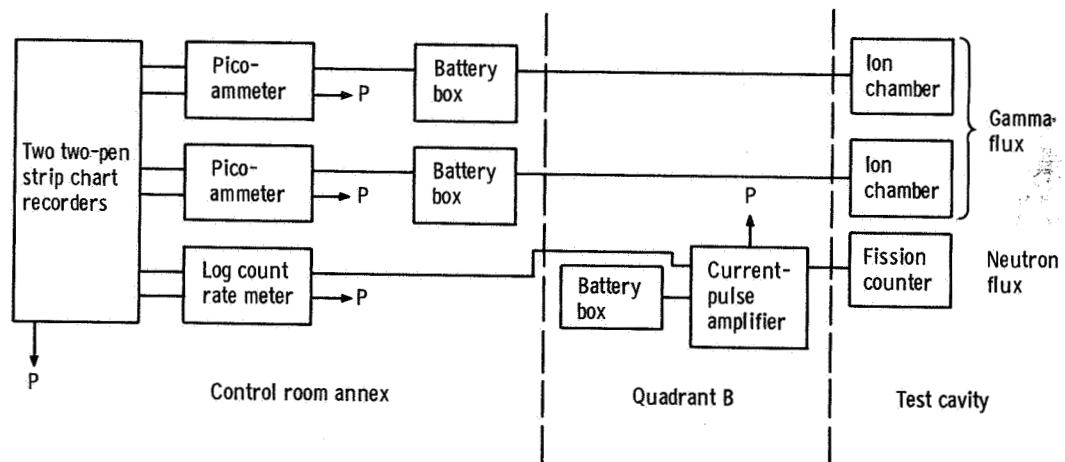


Figure 11. - Nuclear instrumentation for fission counter and ion chambers. Power source, 110 to 120 volts, 60 cycle, single-phase power.

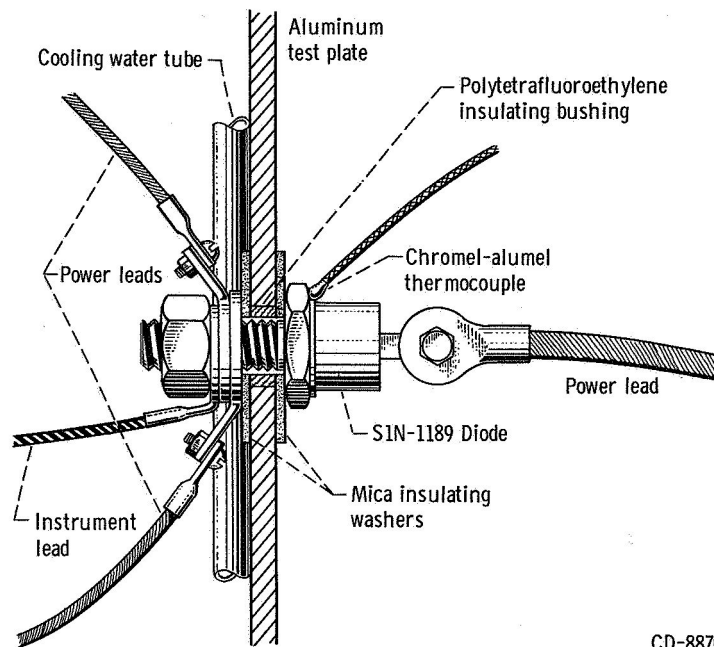


Figure 12. - Diode installation on test plate.

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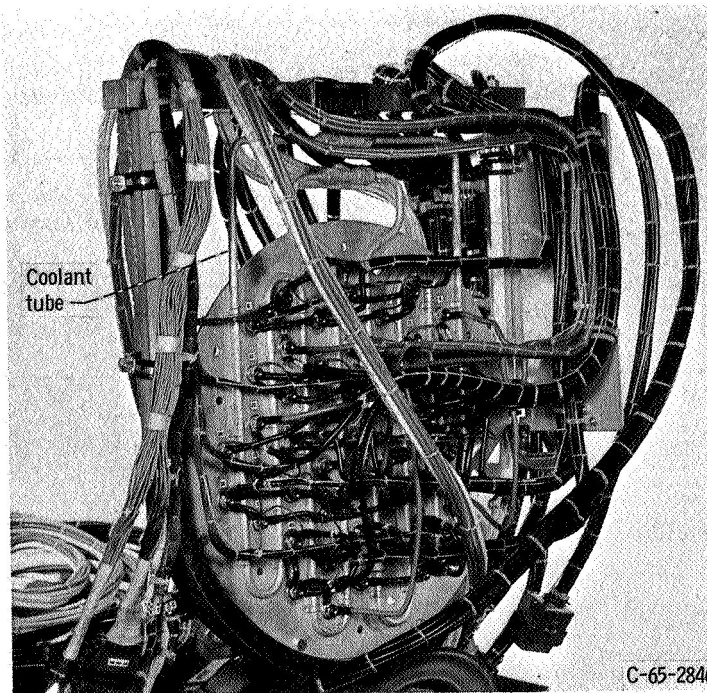


Figure 13. - Water-cooled test plate with diodes.

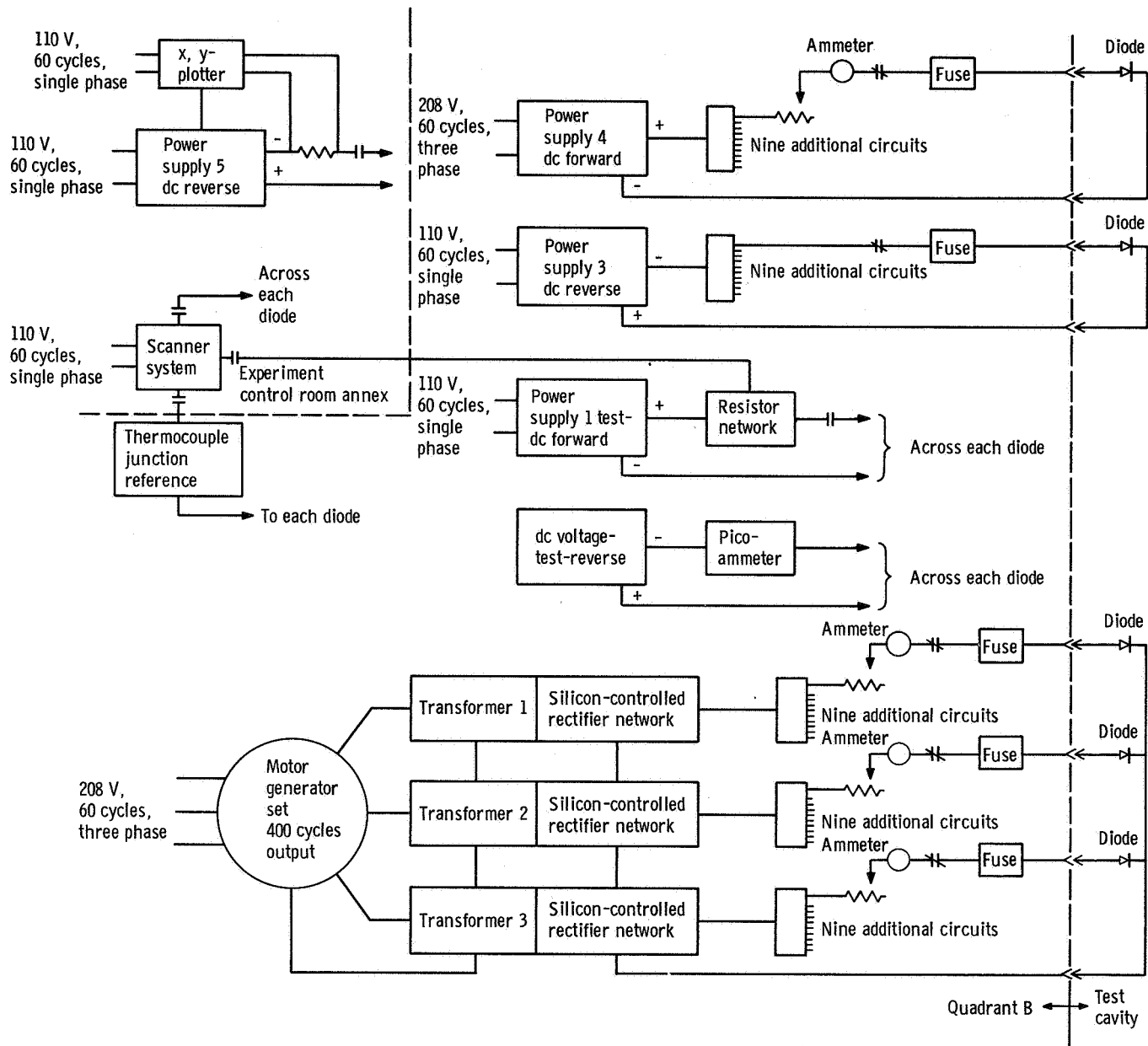


Figure 14. - Diode-irradiation-test instrumentation.

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